



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :

H03M 1/00

A2

(11) International Publication Number:

WO 98/00921

(43) International Publication Date:

8 January 1998 (08.01.98)

(21) International Application Number: PCT/GB97/01762

(22) International Filing Date: 30 June 1997 (30.06.97)

(30) Priority Data:

9613673.4

28 June 1996 (28.06.96)

GB

(71) Applicant (for all designated States except US): SCIENTIFIC GENERICS LIMITED [GB/GB]; Harston Mill, Harston, Cambridgeshire CB2 5NH (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): ELY, David, Thomas, Eliot [GB/GB]; 45 Coleridge Road, Cambridge CB1 3PH (GB). DAMES, Andrew, Nicholas [GB/GB]; 74 Defreville Avenue, Cambridge CB4 1HU (GB).

(74) Agent: BERESFORD, Keith, Denis, Lewis; Beresford & Co., 2-5 Warwick Court, High Holborn, London WC1R 5DJ (GB).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

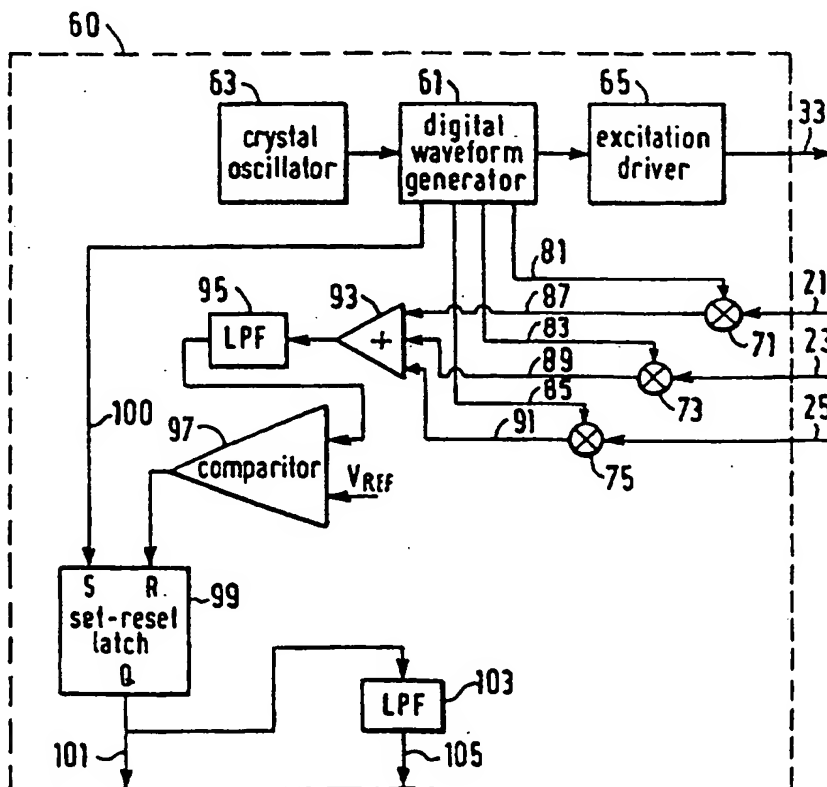
Published

Without international search report and to be republished upon receipt of that report.

(54) Title: APPARATUS AND METHOD FOR PROCESSING SIGNALS OBTAINED FROM A POSITION ENCODER

(57) Abstract

Processing circuitry is provided for processing a plurality of signals received from sense coils (21, 23 and 25) forming part of a position encoder used to encode the relative positions of two relatively movable members. The position encoder is such that each of the plurality of signals from the sense coils varies sinusoidally with the relative position of the members but out of phase with respect to each other. The processing apparatus comprises mixers (71, 73 and 75) for multiplying each of the received signals with one of a corresponding plurality of periodic time varying signals, each having the same predetermined period and a different predetermined phase, and an adder (93) for adding the signals from the mixers. The phase of the mixing signals are chosen so that the output signal from the adder contains a single periodic component having the predetermined period whose phase varies with the relative position of the two members.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|----|--------------------------|----|--|----|--|----|--------------------------|
| AL | Albania | ES | Spain | LS | Lesotho | SI | Slovenia |
| AM | Armenia | FI | Finland | LT | Lithuania | SK | Slovakia |
| AT | Austria | FR | France | LU | Luxembourg | SN | Senegal |
| AU | Australia | GA | Gabon | LV | Latvia | SZ | Swaziland |
| AZ | Azerbaijan | GB | United Kingdom | MC | Monaco | TD | Chad |
| BA | Bosnia and Herzegovina | GE | Georgia | MD | Republic of Moldova | TG | Togo |
| BB | Barbados | GH | Ghana | MG | Madagascar | TJ | Tajikistan |
| BE | Belgium | GN | Guinea | MK | The former Yugoslav Republic of Macedonia | TM | Turkmenistan |
| BF | Burkina Faso | GR | Greece | ML | Mali | TR | Turkey |
| BG | Bulgaria | HU | Hungary | MN | Mongolia | TT | Trinidad and Tobago |
| BJ | Benin | IE | Ireland | MR | Mauritania | UA | Ukraine |
| BR | Brazil | IL | Israel | MW | Malawi | UG | Uganda |
| BY | Belarus | IS | Iceland | MX | Mexico | US | United States of America |
| CA | Canada | IT | Italy | NE | Niger | UZ | Uzbekistan |
| CF | Central African Republic | JP | Japan | NL | Netherlands | VN | Viet Nam |
| CG | Congo | KE | Kenya | NO | Norway | YU | Yugoslavia |
| CH | Switzerland | KG | Kyrgyzstan | NZ | New Zealand | ZW | Zimbabwe |
| CI | Côte d'Ivoire | KP | Democratic People's Republic of Korea | PL | Poland | | |
| CM | Cameroon | KR | Republic of Korea | PT | Portugal | | |
| CN | China | KZ | Kazakhstan | RO | Romania | | |
| CU | Cuba | LC | Saint Lucia | RU | Russian Federation | | |
| CZ | Czech Republic | LI | Liechtenstein | SD | Sudan | | |
| DE | Germany | LK | Sri Lanka | SE | Sweden | | |
| DK | Denmark | LR | Liberia | SG | Singapore | | |
| EE | Estonia | | | | | | |

APPARATUS AND METHOD FOR PROCESSING SIGNALS
OBTAINED FROM A POSITION ENCODER

The present invention relates to an apparatus and method
5 for processing signals received from a position encoder.
The present invention may be used to determine the
position of two relatively movable members from signals
received from a position encoder used to determine their
relative positions, wherein the positional information
10 is encoded within the amplitude of a number of carrier
signals output from the position encoder.

Many types of non-contact linear and rotary position
encoders have been proposed for generating signals
15 indicative of the position of two relatively movable
members. Typically, one of the members carries one or
more sense coils and the other carries one or more
magnetic field generators. The magnetic field generators
and the sense coils are arranged such that the amount of
20 magnetic coupling between the magnetic field generators
and the sense coils varies as a function of the relative
position of the two members.

In some of these non-contact position encoders, the sense
25 windings and the magnetic field generators are designed
to try and make the output signal vary linearly with the
relative position between the two members, since this
reduces the complexity of the signal processing required
to determine the positional information. However, it is
30 difficult to design a system which is exactly linear and
they are usually relatively sensitive to variations in
the gap between the sense coils and the magnetic field
generators.

The applicant's earlier International Patent Application WO95/31696 discloses several examples of similar non-contact position encoders in which the output signal from each sense coil varies sinusoidally as a function of the relative position of two movable members. However, in order to derive the positional information, more complex processing of the received signals is required. In particular, where two phase-quadrature sense coils are used, the signal from each is demodulated and a ratiometric arc-tangent calculated in order to obtain the positional information. Although the ratiometric arc-tangent calculation reduces the system's sensitivity to variations in the gap between the two relatively movable members, it requires relatively complex processing calculations which are usually performed by a microprocessor under software control.

An aim of the present invention is to provide an alternative method and apparatus for processing signals which vary sinusoidally with the relative position between the two relatively movable members.

According to one aspect the present invention provides processing circuitry for processing signals received from a position encoder used to determine the relative position between two relatively movable members in which the received signals are combined with an intermediate frequency signal having a phase which depends upon the phase of the received signal.

According to another aspect, the present invention provides a processing apparatus for processing a number of signals received from a position encoder used to encode the relative positions of a number of relatively movable members, wherein each of the received signals

varies in a similar manner with said relative position but having differing phases, the apparatus comprising: means for combining each of the received signals with a respective one of a corresponding number of the periodically varying signals, each varying in a similar manner but with a different predetermined phase; and means for adding the combined signals to provide an output signal, and wherein the predetermined phases of said periodically varying signals are determined so that said output signal from said adding means contains a single periodically varying component whose phase varies with said relative position.

According to another aspect, the present invention provides a method of processing a number of signals received from a position encoder used to encode the relative positions of a number of relatively movable members, wherein each of the received signals varies in a similar manner with said relative position, but out of phase with respect to each other, the method comprising the steps of: combining each of the received signals with a respective one of a corresponding number of periodically varying signals, each varying in a similar manner but with a different predetermined phase; and adding the combined signals to provide an output signal, and wherein the predetermined phases of the periodically varying signals are determined so that the output signal contains a single periodically varying component whose phase varies with said relative position.

The present invention also provides a position detector comprising a number of sensing circuits, each extending over a measurement path and being offset from each other; generator means, being mounted for relative movement over the measurement path, for generating a signal in each of

the sensing circuits which varies as a function of the relative position between said generating means and the sensing circuit, whereby, the phase of each of said generated signals is different due to the offset between each of said sensor circuits over said measurement path; means for combining each of the received signals with a respective one of a corresponding number of periodically varying signals, each varying in a similar manner but with a different predetermined phase; and means for adding the signals from the combining means to provide an output signal; wherein said predetermined phases of said periodically varying signals are determined so that said output signal from said adding means contains a single periodic component whose phase varies with the relative position between said generator means and said sensing circuit.

Preferably the sensing circuits are evenly spaced over the measurement path and the predetermined phases of the periodically varying signals are made equal in magnitude to the phase of the signals from the corresponding sensing circuit, since these can be easily calculated in advance.

Exemplary embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 schematically illustrates a rotating shaft having a position encoder mounted relative thereto, for encoding the position of the rotatable shaft;

Figure 2a is a schematic view of three sense coils formed on a printed circuit board which forms part of the position encoder shown in Figure 1;

Figure 2b shows a top layer of printed conductors forming part of the printed circuit board shown in Figure 2a;

5 Figure 2c shows the bottom layer of printed conductors forming part of the printed circuit board shown in Figure 2a;

10 Figure 3 illustrates the form of an electrically resonant circuit forming part of the position encoder shown in Figure 1;

Figure 4 illustrates the way in which the peak amplitude of the signal induced in each sense coil varies with the angular position of the rotatable shaft;

15 Figure 5 is a schematic representation of excitation and processing circuitry embodying the present invention for determining the angular position of the rotatable shaft;

20 Figure 6a illustrates the way in which one of the output signals from the processing circuitry shown in Figure 5 varies with time;

25 Figure 6b illustrates the way in which the duty ratio of the output signal shown in Figure 6a varies with the angular position of the rotatable shaft;

30 Figure 6c illustrates the way in which the ratio of an output voltage from the processing circuitry shown in Figure 5 to the supply voltage, varies with the angular position of the rotatable shaft;

Figure 7a shows a circuit diagram of a part of the excitation circuitry schematically shown in Figure 5;

Figure 7b shows a circuit diagram of the rest of the excitation circuitry schematically shown in Figure 5;

Figure 7c shows a circuit diagram of part of the processing circuitry schematically shown in Figure 5; and

Figure 7d shows a circuit diagram of the rest of the processing circuitry schematically shown in Figure 5.

Figure 1 schematically shows a shaft 1 which is rotatable about its axis as represented by the arrow 7 and which passes through a bearing 3 provided in a support wall 5. A first printed circuit board 9 carrying a magnetic field generator (not shown), is mounted for rotation (as represented by arrow 13) with the shaft 1 via a bushing 11 next to a second printed circuit board 15 (shown in cross-section) which carries a number of sense coils (not shown) and an excitation coil (not shown). The second printed circuit board 15 is fixed to the support wall 5 and has a central hole 16 through which the rotatable shaft 1 passes. Preferably, the separation between the circuit 59 and the circuit board 15 is between 0.1 and 4 mm in order to obtain reasonably large signals from the sense coils (not shown).

The arrangement of the magnetic field generator on circuit board 9 and the sense coils on circuit board 15 are such that when the magnetic field generator generates a magnetic field, a signal is induced in each of the sense coils, the peak amplitude of which varies sinusoidally with the angle of rotation of the shaft 1. The signals induced in the sense coils are supplied to processing circuitry (not shown) where the rotational angle of the rotatable shaft 1 is determined.

In this embodiment, three periodic sense coils are used which extend circumferentially around the circuit board 15. Each sense coil comprises three periods of windings which are circumferentially spaced apart by 20° . Figure 5 2a shows the conductors on the printed circuit board 15 which form these three sense coils 21, 23 and 25. Each sense coil 21, 23 and 25 comprises six loops of series connected conductors, connected such that adjacent loops are wound in the opposite sense. This makes the sense 10 coils relatively immune to background electromagnetic interference. The angle over which one period of each sense coil extends is 120° . The ends of the sense coils 21, 23 and 25, are connected to processing circuitry (not shown) by the twisted wire pairs 27, 29 and 31 15 respectively. Figure 2a also shows the conductor which forms the excitation coil 33 which is connected to excitation circuitry (not shown) by twisted wire pair 35.

Figures 2b and 2c illustrate the way in which the sense 20 coils 21, 23 and 25 and the excitation coil 33 shown in Figure 2a are formed by a top and bottom layer of printed conductors formed on the printed circuit board 15. The conductors on the top and bottom layers are connected, where appropriate, through via holes, some of which are 25 referenced 37.

Figure 3 shows the conductor on the printed circuit board 9 which forms the magnetic field generator 41. In this embodiment, the magnetic field generator comprises an 30 electrically resonant circuit 41 having an inductor coil 43 and a capacitor 45. Other types of magnetic field generators could be used, such as, a short circuit coil or a conductive plate.

35 The principle of operation of the position encoder formed

by the sense coils 21, 23 and 25, the excitation coil 33 and the resonant circuit 41 will now be briefly described. A more detailed explanation of the principle of operation of this position encoder and similar position encoders can be found in the applicant's earlier International Patent Application W095/31696, the content of which is hereby incorporated by reference.

In operation, an AC excitation current is applied to the excitation coil 33 for energising the resonant circuit 41. In response, the resonant circuit 41 generates a magnetic field which induces an Electro-Motive Force (EMF) in each of the sense coils 21, 23 and 25, the amplitude of which varies sinusoidally with the relative position between the resonator and the sense coil. Preferably, the fundamental frequency of the excitation current applied to the excitation coil 33 corresponds with the resonant frequency of the resonant circuit 41, since this provides the maximum signal output.

Figure 4 illustrates the way in which the peak amplitude (\hat{E}) of the EMF's generated in the sense coils 21, 23 and 25 vary with the rotation angle (θ) of the resonant circuit 41. As shown, the respective peak amplitudes 51, 53 and 55 vary sinusoidally and repeat every third of a revolution of the resonant circuit 41 (and hence of the rotatable shaft 1) and are separated by $1/6$ of a period from each other. Therefore, the angular position of the rotatable shaft 1 can be determined unambiguously through 120° by suitable processing of the induced signals. This position encoder would, therefore, be suitable for determining the angular position of a throttle valve in an engine, which only rotates through 90 degrees.

Figure 5 schematically represents excitation and

processing circuitry 60 embodying the present invention, which is used to excite the excitation coil 33 and to process the signals induced in the sense coils 21, 23 and 25. The excitation signal is generated by the digital waveform generator 61 which receives an oscillating input from a crystal oscillator 63. In this embodiment, the excitation signal is a squarewave voltage having a fundamental frequency F_0 (e.g. 1MHz) which is applied to an excitation driver 65 which drives the excitation coil 33.

As mentioned above, the energisation of the excitation coil energises the resonant circuit 41, which in turn generates a magnetic field which induces an EMF in each of the sense coils. The EMF's induced in the sense coils 21, 23 and 25 will include the following components respectively:

$$\begin{aligned}
 EMF_{21} &= A_0 \cos\left[\frac{2\pi\theta}{\lambda}\right] \cos[2\pi F_0 t] \\
 EMF_{23} &= A_0 \cos\left[\frac{2\pi\theta}{\lambda} + \frac{\pi}{3}\right] \cos[2\pi F_0 t] \\
 EMF_{25} &= A_0 \cos\left[\frac{2\pi\theta}{\lambda} + \frac{2\pi}{3}\right] \cos[2\pi F_0 t]
 \end{aligned} \tag{1}$$

Where A_0 is the coupling coefficient between the resonant circuit 41 and the sensor coils 21, 23 and 25, which depends upon, among other things, the separation between the sensor coils 21, 23 and 25 and the resonant circuit 41; λ is the repeat angle, ie. the angle over which one period of each sense coil extends, which, in this embodiment, equals 120° ; θ is the rotation angle of the resonant circuit 41 (and hence of the rotatable shaft 1); and F_0 is the fundamental frequency of the excitation

current applied to the excitation coil 33. There is an additional phase term in the amplitude component of the EMF induced in sense coils 23 and 25 due to the circumferential offset between the sense coils 21, 23 and 25 (the signal induced in sense coil 21 acting as the reference phase). These phase terms will be referred to hereinafter as the sense signal phase.

The induced EMF's are applied to mixers 71, 73 and 75 respectively, where they are multiplied with signals 81, 83 and 85 respectively. Each of the mixing signals 81, 83 and 85 comprises two periodic time varying components. In this embodiment the first component (V_1) is a squarewave corresponding to the squarewave voltage applied to the excitation coil 33 but having a 90° offset to compensate for the phase change due to the resonator 41. In this embodiment, the second component (V_2) is also a squarewave signal but has a lower fundamental frequency F_{IF} (e.g. 10.417 KHz) and, in this embodiment, a phase the same as the above mentioned sense signal phase from the corresponding sense coil 21, 23 or 25. The first component effectively demodulates the amplitude modulated EMF induced in the corresponding sense coil and the second component re-modulates it to an intermediate frequency F_{IF} .

The advantage of using squarewave signals for mixing with the incoming signal from the corresponding sense coil is that the digital waveform generator 61 can multiply these two signals together by simply performing an exclusive-or (XOR) function on the two squarewave components. This is because the high level of the squarewave signal represents positive one and the low level represents negative one. This can be easily verified by considering the truth table of an XOR gate. Additionally, by using

squarewave mixing signals, the mixers 71, 73 and 75 can be implemented using an analog CMOS IC switch.

As those who are familiar with Fourier analysis of signals will appreciate, a periodic squarewave can be represented by the sum of a fundamental sinusoid having the same period as the squarewave and higher order odd harmonics of the fundamental frequency. Therefore, the multiplication being performed in the mixers 71, 73 and 75 can be expressed as follows:

$$\begin{aligned}
 & (A_0 \cos\{\frac{2\pi\theta}{\lambda}\} \cos\{2\pi F_0 t\}) \times \\
 M_{71} = & (\cos\{2\pi F_0 t\} + \text{ODD HARMONICS}) \times \\
 & (\cos\{2\pi F_{IF} t\} + \text{ODD HARMONICS}) \\
 & (A_0 \cos\{\frac{2\pi\theta}{\lambda} + \frac{\pi}{3}\} \cos\{2\pi F_0 t\}) \times \\
 M_{73} = & (\cos\{2\pi F_0 t\} + \text{ODD HARMONICS}) \times \\
 & (\cos\{2\pi F_{IF} t + \frac{\pi}{3}\} + \text{ODD HARMONICS}) \\
 & (A_0 \cos\{\frac{2\pi\theta}{\lambda} + \frac{2\pi}{3}\} \cos\{2\pi F_0 t\}) \times \\
 M_{75} = & (\cos\{2\pi F_0 t\} + \text{ODD HARMONICS}) \times \\
 & (\cos\{2\pi F_{IF} t + \frac{2\pi}{3}\} + \text{ODD HARMONICS})
 \end{aligned} \tag{2}$$

Performing this multiplication and rearranging the terms (ignoring the high frequency odd harmonics) results in the following expressions for the outputs M_{71} , M_{73} and M_{75}

12

of the mixers 71, 73 and 75:

$$\begin{aligned}
 M_{71} &= \frac{A_0}{4} (\cos[2\pi F_{IF}t + \theta] + \cos[2\pi F_{IF}t - \theta]) \\
 M_{73} &= \frac{A_0}{4} (\cos[2\pi F_{IF}t + \theta + \frac{2\pi}{3}] + \cos[2\pi F_{IF}t - \theta]) \\
 M_{75} &= \frac{A_0}{4} (\cos[2\pi F_{IF}t + \theta + \frac{4\pi}{3}] + \cos[2\pi F_{IF}t - \theta]) \quad (3)
 \end{aligned}$$

These signals are then added together in the adder 93 to give:

$$V_{OUT} = \frac{3A_0}{4} (\cos[2\pi F_{IF}t - \theta]) \quad (4)$$

5

Therefore the output signal from the adder 93 includes a single sinusoid at the intermediate frequency whose phase varies with the angular position (θ) of the rotatable shaft. As those skilled in the art will appreciate, the other intermediate frequency components cancel due to the particular choice of the phase of each of the intermediate frequency mixing signals. The output V_{OUT} from the adder will also contain high frequency odd harmonic components, but these are removed by the low pass filter 95. The single intermediate frequency component in V_{OUT} is then supplied to the comparator 97, where it is converted into a corresponding squarewave by comparing it with a reference voltage V_{REF} .

20

In order to measure the phase of this single intermediate component, the squarewave signal output by the comparator 97 is applied to the reset input (R) of a set-reset latch 99. The set input (S) of the latch 99 receives a

squarewave signal 100 generated by the digital waveform generator 61. In this embodiment, the squarewave signal 100 has the same fundamental frequency F_{1F} and phase as the second mixing component V_2 applied to mixer 71. The squarewave signal 100 may be passed through a low pass filter corresponding to low pass filter 95 and then compared with the reference voltage V_{REF} prior to being applied to the set input of the latch 99. This reduces the effect of offset errors caused by temperature drift of the electronic components, since both signals applied to the input of the latch 99 will have been processed by similar electronics.

Figure 6a shows the resulting Q output signal 101 from the latch 99. As shown, output signal 101 is a periodic squarewave signal having a period (T_{1F}) the same as the second mixing components V_2 applied to the mixers 71, 73 and 75 and a duty ratio which varies with the angular position (θ) of the rotatable shaft 1. Figure 6b illustrates the way in which the duty ratio of the output signal 101 (V_{101}) varies with the rotation angle of the rotatable shaft. As shown, the duty ratio varies in a sawtooth manner, repeating every 120° of rotation of the rotatable shaft 1.

In this embodiment the output signal 101 from the latch 99 is also applied to the input of a low pass filter 103 which removes all the time varying components to leave an output signal 105 representing the amount of DC signal present in the output signal 101. As shown in Figure 6c, the ratio of the output signal 105 (V_{105}) to the supply voltage V_{supply} also varies in a sawtooth manner (with a maximum value of 0.6), repeating every 120° of rotation of the rotatable shaft 1.

Figures 7a-7d illustrate a circuit diagram of the excitation and processing circuitry 60 schematically shown in Figure 5. In particular, Figure 7a is a circuit diagram showing the crystal oscillator 63 and the digital waveform generator 61. As shown, the crystal oscillator 63 generates a 4 MHz signal which is applied to various counters and logic gates of the digital waveform generator 61. The waveform generator 61 outputs two signals TXA and TXB which are applied to the excitation driver 65 shown in Figure 7b and signals 100, 81, 83 and 85 which are used in the processing circuitry. Figure 7b illustrates the circuit diagram of the excitation driver 65 which receives the signals TXA and TXB from the digital waveform generator 61 and outputs the excitation signal to the twisted wire pair 35 which, as shown in Figure 2a, is connected to the excitation coil 33.

Figure 7c is a circuit diagram showing part of the processing circuitry shown in Figure 5. As shown, the ends of the twisted wire pairs 27, 29 and 31 are connected to the input of a triple change over CMOS switch which forms the mixers 71, 73 and 75. The CMOS switch also receives signals 81, 83 and 85 output from the digital waveform generator 61 shown in Figure 7a. Figure 7c also shows the adder 93 which adds the signals from the mixers 71, 73 and 75, the low pass filter 95 which filters out the high frequency odd harmonic components from the output of the adder 93 and the comparator 97 which compares the filtered output signal with a reference voltage V_{REF} . As illustrated in Figure 7c, the reference voltage V_{REF} equals 2.5 volts, since the input signal varies between zero and positive five volts.

Figure 7d shows a circuit diagram of the rest of the processing circuitry shown in Figure 5. In particular,

Figure 7d shows the set-reset latch 99 and the low pass filter 103 used to filter the output signal 101 from the latch 99 to produce the output signal 105.

5 As those skilled in the art will appreciate, there are a number of advantages of the processing circuitry described above as compared with, for example, the processing circuitry described in the applicant's earlier International Application W095/31696. In particular, the
10 processing circuitry described above is able to produce an output signal which varies in dependence upon the rotational position (θ) of the rotatable shaft which is relatively insensitive to variations in the gap between the sense coils 21, 23 and 25 and the resonant circuit
15 41. This is because the phase of the output signal from the low pass filter 95 does not depend upon the abovementioned coupling coefficient A_0 . The processing circuitry 60 described above also has the advantage that it continuously outputs a signal which is indicative of
20 the rotational angle of the rotatable shaft 1. Whereas, with the processing circuitry described in W095/31696, the abovementioned arc-tangent calculation has to be performed each time a position measurement is required in order to generate an output signal.

25 Although the embodiment described above uses three sense coils, the processing circuitry could be adapted to receive and process signals from any number of sense coils. Additionally, as those skilled in the art will
30 appreciate, it is not necessary for the sense coils to be evenly spaced over the measurement path. Further still, a different weighting could be applied to the signals output from the different mixers.

35 In the general case where there are n sense coils spaced

over the measurement direction and a weighting is applied to the output of each mixer, then the output of the low pass filter 95 will have the following general form:

$$\begin{aligned}
 V_{OUT} = & \frac{A_0}{4} \cos[2\pi F_{IF} t + \theta] (w_0 + w_1 \cos[\phi_1 + \psi_1] + \dots + w_{n-1} \cos[\phi_{n-1} + \psi_{n-1}]) \\
 & + \frac{A_0}{4} \cos[2\pi F_{IF} t - \theta] (w_0 + w_1 \cos[\phi_1 - \psi_1] + \dots + w_{n-1} \cos[\phi_{n-1} - \psi_{n-1}]) \\
 & - \frac{A_0}{4} \sin[2\pi F_{IF} t + \theta] (w_1 \sin[\phi_1 - \psi_1] + \dots + w_{n-1} \sin[\phi_{n-1} - \psi_{n-1}]) \\
 & - \frac{A_0}{4} \sin[2\pi F_{IF} t - \theta] (w_1 \sin[\phi_1 + \psi_1] + \dots + w_{n-1} \sin[\phi_{n-1} + \psi_{n-1}])
 \end{aligned}$$

- 5 Where w_i is the weighting applied to the output signal from mixer i ; ϕ_i is the phase of the intermediate frequency component applied to mixer i and ψ_i is the abovementioned sense signal phase of the signal received from sense coil i . As those skilled in the art will appreciate, there are many different values of w_i , ϕ_i and ψ_i which will result in V_{OUT} reducing to a single sinusoidal component which varies with the rotation angle (θ) of the rotatable shaft 1. When the weights (w_i) are the same, and when n sense coils are evenly spaced over the measurement path, the following values of ϕ_i will result in V_{OUT} reducing to a signal sinusoid:

$$|\phi_i| = \psi_i = \frac{i\pi}{n}$$

Although the position encoder described in the above

embodiment is a rotary position encoder, the above processing circuitry could be used for processing the signals from a linear position encoder or a radial position encoder, such as those described in the
5 applicant's earlier International Patent Application WO95/31696.

Although the embodiment described uses a non-contact inductive position encoder, as those skilled in the art
10 will appreciate, the processing circuitry described above could be used to process the signals from a position encoder which uses capacitive coupling or to process the signals from a position encoder which has direct contact between the two relatively movable members.

15

CLAIMS:

1. A processing apparatus for processing a plurality of signals received from a position encoder used to
5 encode the relative positions of two relatively movable members, wherein each of said plurality of signals varies sinusoidally with said relative position and out of phase with respect to each other, the apparatus comprising:
means for multiplying each of said received signals
10 with a respective one of a corresponding plurality of periodic time varying signals, each having the same predetermined period and a different predetermined phase; and
means for adding the signals from said multiplying
15 means to provide an output signal;
wherein said predetermined phases of said periodic time varying signals are determined so that said output signal from said adding means contains a single periodic component having said predetermined period whose phase
20 varies with said relative position.
2. An apparatus according to claim 1, wherein the predetermined phases of said periodic time varying signals are determined such that their magnitude equals
25 the phase of the corresponding received signal with which it is multiplied.
3. An apparatus according to claim 1 or 2, wherein each of said plurality of signals which vary sinusoidally with
30 said relative position, amplitude modulates a periodic time varying carrier signal having a period less than said predetermined period of said other periodic time varying signals.
- 35 4. An apparatus according to claim 3, wherein said

multiplying means is arranged to multiply each of said received signals with a periodic time varying signal having a period equal to the period of said carrier signal.

5

5. An apparatus according to claim 4, further comprising a waveform generator which is arranged to generate each of said periodic time varying signals.

10 6. An apparatus according to claim 5, wherein each of said periodic time varying signals are squarewave signals.

15 7. An apparatus according to claim 6, wherein said waveform generator is arranged to combine the two different periodic time varying signals prior to multiplication with the respective received signal using an XOR gate.

20 8. An apparatus according to claim 6 or 7, wherein said multiplying means comprises a CMOS IC switch.

25 9. An apparatus according to any preceding claim, further comprising means for filtering said output signal to remove components not having said predetermined period.

30 10. An apparatus according to claim 9, wherein the output of said filtering means is substantially sinusoidal having said predetermined period, and wherein said apparatus further comprises means for converting said sinusoidal signal into a squarewave signal having said predetermined period and said phase which varies with said relative position.

35

11. An apparatus according to claim 10, wherein said converting means comprises a comparator for comparing said sinusoidal signal with a reference signal.

5 12. An apparatus according to claim 10 or 11, further comprising means for processing said squarewave signal having said predetermined period whose phase varies with said relative position to output a different squarewave signal whose duty ratio varies with said relative phase.

10

13. An apparatus according to claim 12, wherein said processing means comprises a set-reset latch.

14. A method of processing a plurality of signals
15 received from a position encoder used to encode the relative positions of two relatively movable members, wherein each of the plurality of signals varies sinusoidally with said relative position and out of phase with respect to each other, the method comprising the
20 steps of:

 multiplying each of the received signals with respective one of the corresponding plurality of periodic time varying signals, each having the same predetermined period and a different predetermined phase; and

25 adding the signals from the multiplying step to provide an output signal;

 wherein said predetermined phases of said periodic time varying signals are determined so that said output signal from said adding step contains a single periodic
30 component having said predetermined period whose phase varies with said relative position.

15. A method according to claim 14, wherein the predetermined phases of said periodic time varying
35 signals are determined such that their modulus equals the

phase of the corresponding received signal with which it is multiplied.

16. A method according to claim 13 or 14, wherein each
5 of said plurality of signals which vary sinusoidally with said relative position, amplitude modulates a periodic time varying carrier signal having a predetermined period less than said predetermined period of said other periodic time varying signals.

10

17. A method according to claim 16, wherein said multiplying step multiplies means is arranged to multiple each of said received signals with a periodic time varying signal having a period equal to the period of
15 said carrier signal.

18. A method according to claim 17, further comprising the step of generating each of said periodic time varying signals.

20

19. A method according to claim 18, wherein each of the periodic time varying signals is a squarewave signal.

20. A method according to claim 19, wherein said the two
25 different periodic time varying signals are combined prior to multiplication with the respective received signal using an XOR gate.

21. A method according to claim 19 or 20, wherein a CMOS
30 IC switch is used to multiply said two different time varying signals.

22. A method according to any of claims 14 to 21, further comprising the step of filtering said output
35 signal to remove components not having said predetermined

period.

23. A method according to claim 22, wherein the output of said filtering step is a sinusoidal signal having said predetermined period, and wherein said method further comprises the step of converting said sinusoidal signal into a squarewave signal having said predetermined period and said phase which varies with said relative position.
24. A method according to claim 23, wherein said converting step compares said sinusoidal signal with a reference signal.
25. A method according to claim 23 or 24, further comprising the step of processing said squarewave signal having said predetermined period whose phase varies with said relative position to output a different squarewave signal whose duty ratio varies with said relative phase.
26. A method according to claim 25, wherein said processing step uses a set-reset latch.
27. A position detector comprising:
a plurality of sensing circuits, each extending over a measurement path and being offset from each other over said measurement path;
generator means, being mounted for relative movement over said measurement path, for generating a signal in each of said sensing circuits which varies sinusoidally with the relative position between said generating means and said sensing circuit, whereby, the phase of each of said sinusoidally varying signals is different due to the offset between each of said sensor circuits;
means for multiplying each of the signals generated in said plurality of sensing circuits with a respective

23

one of a corresponding plurality of periodic time varying signals, each having the same predetermined period and a different predetermined phase; and

means for adding the signals from said multiplying
5 means to provide an output signal;

wherein said predetermined phases of said periodic time varying signals are determined so that said output signal from said adding means contains a single periodic component having said predetermined period whose phase
10 varies with said relative position.

28. A position detector according to claim 27, wherein said plurality of sensing circuits are inductively coupled to said generator means.

15 29. A position detector according to claim 27, wherein said sensing circuits are capacitively coupled to said generator means.

20 30. A position detector according to any of claims 27 to 29, wherein said sensing circuits extend over a linear path.

25 31. A position detector according to any of claims 27 to 29, wherein said sensing circuits extend in a radial rotary path.

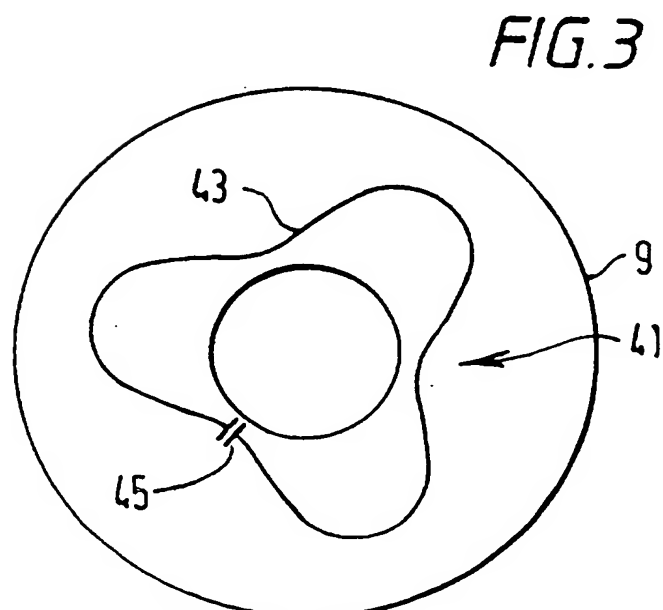
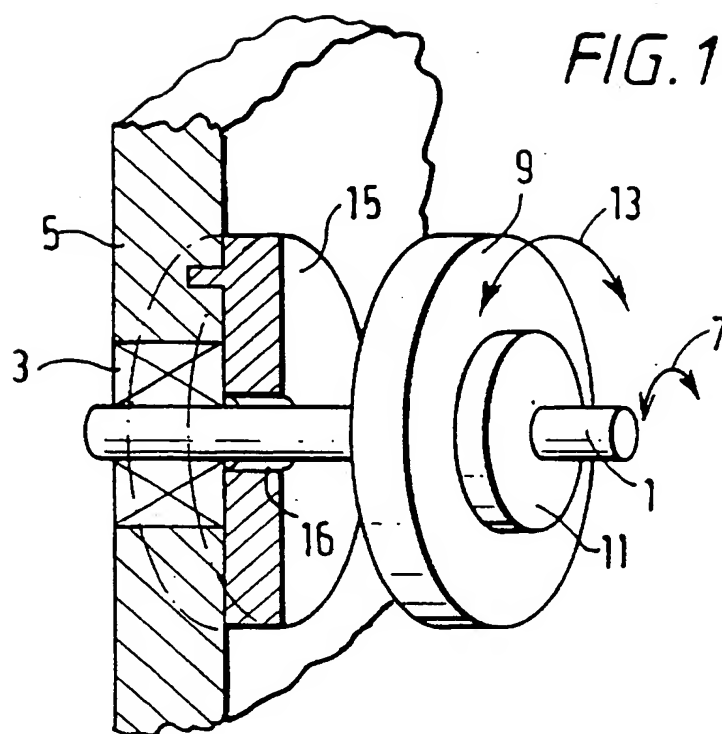
30 32. A position detector according to any of claims 27 to 29, wherein said sensing circuits extend in a radial path.

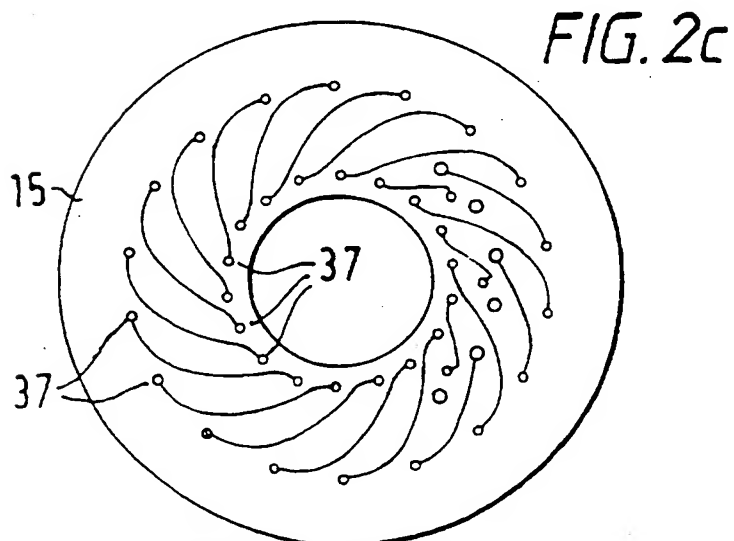
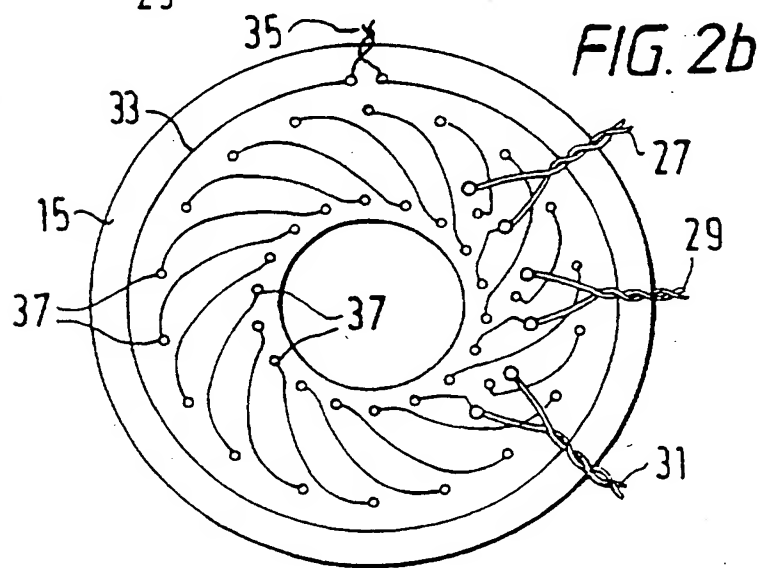
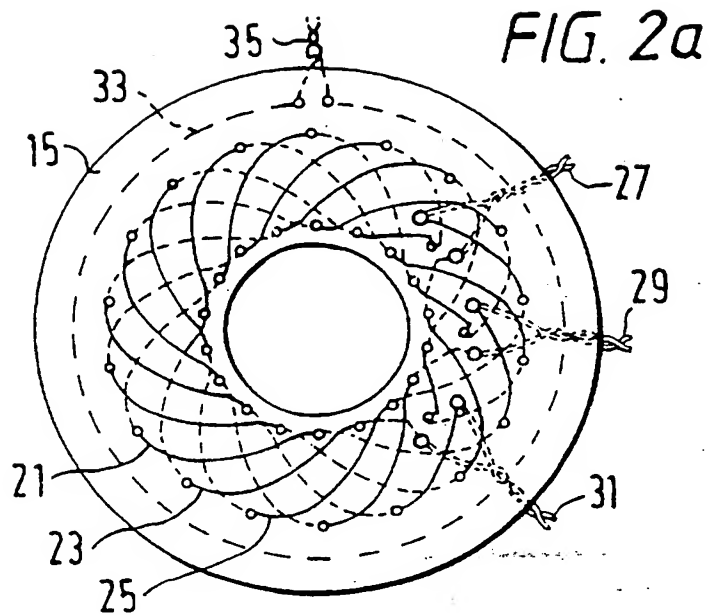
33. Apparatus for processing signals received from a position encoder used to determine the relative positions between a number of relatively movable members in which
35 the position information is encoded within the amplitude

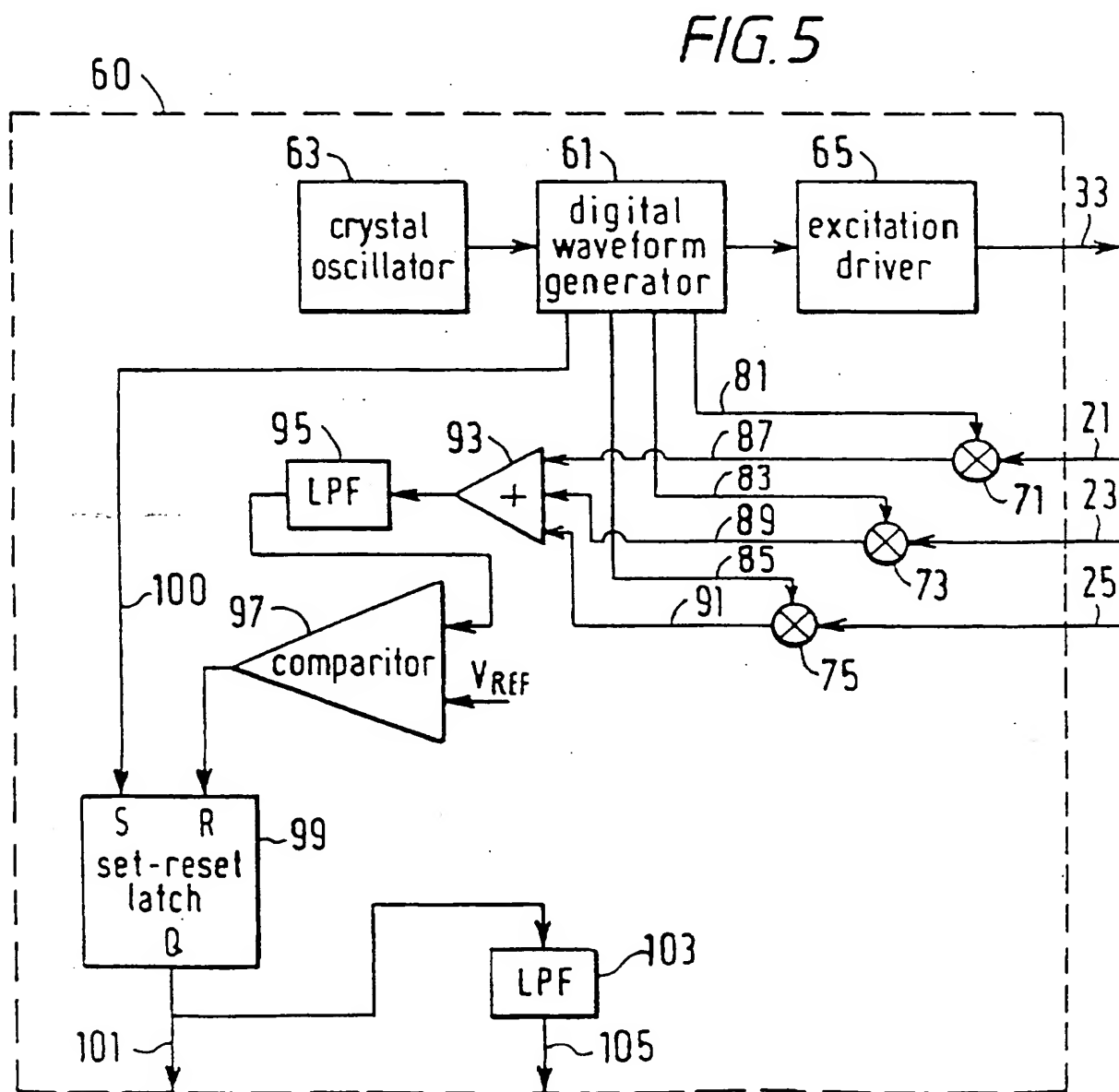
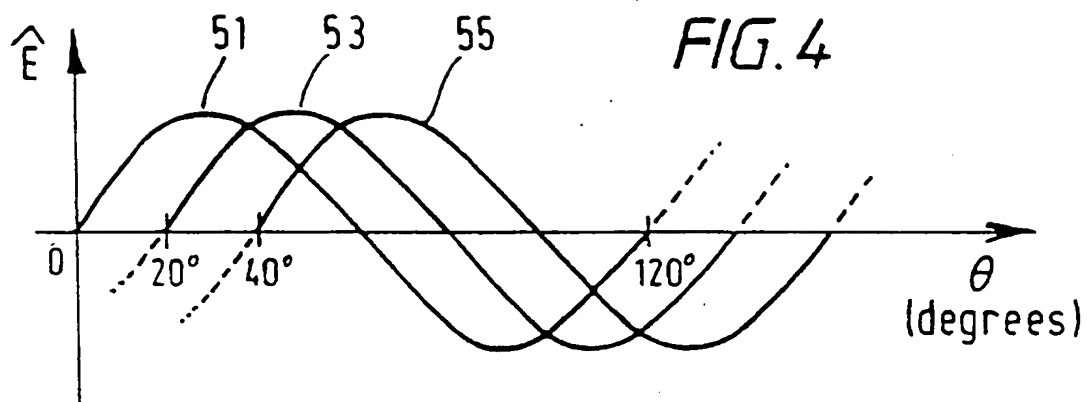
of an amplitude modulated signal, and wherein the apparatus comprises means for demodulating said received signals and means for remodulating said signals with an intermediate frequency signal whose phase depends upon
5 the phase of the corresponding received signal; and combining means for combining the remodulated signals.

34. Apparatus for processing a number of signals received from a position encoder used to encode the
10 relative positions of a number of relatively movable members, wherein each of the received signals varies in a similar manner with said relative position and having different phases, the apparatus comprising: means for combining each of the received signals with a respect to
15 one of a corresponding number of periodically varying signals, each varying in a similar manner but with a different predetermined phase; and means for adding the combined signals to provide an output signal, and wherein the predetermined phases of said periodically varying
20 signals are determined so that said output signal from said adding means contains a single periodically varying component whose phase varies with said relative position.

35. Apparatus according to any of claims 1 to 13 or 27
25 to 34, wherein the modulus of the phase of each of said periodically varying signals is given by $(i\pi)/n$, where n is the number of received signals.







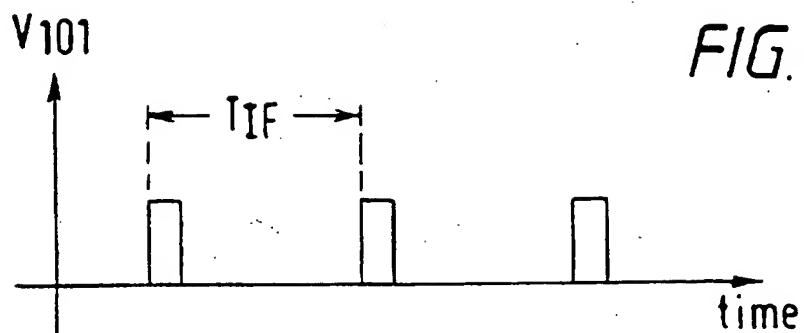


FIG. 6a

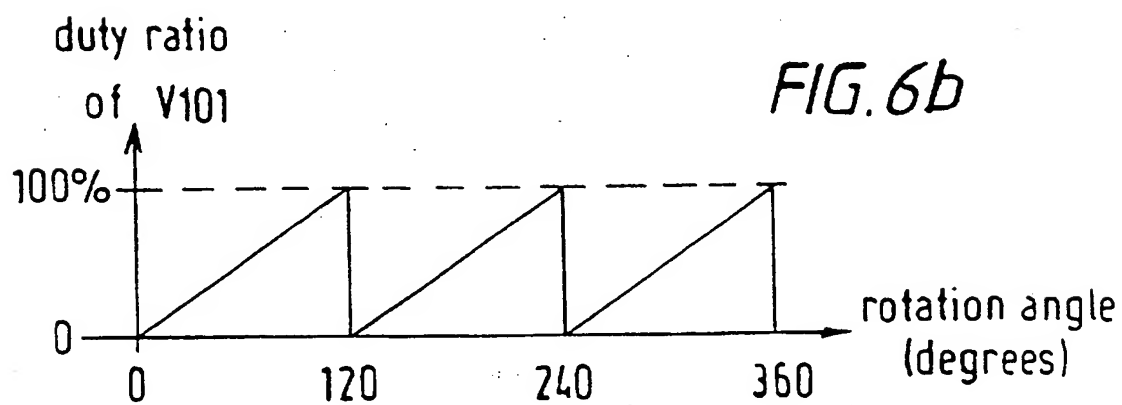


FIG. 6b

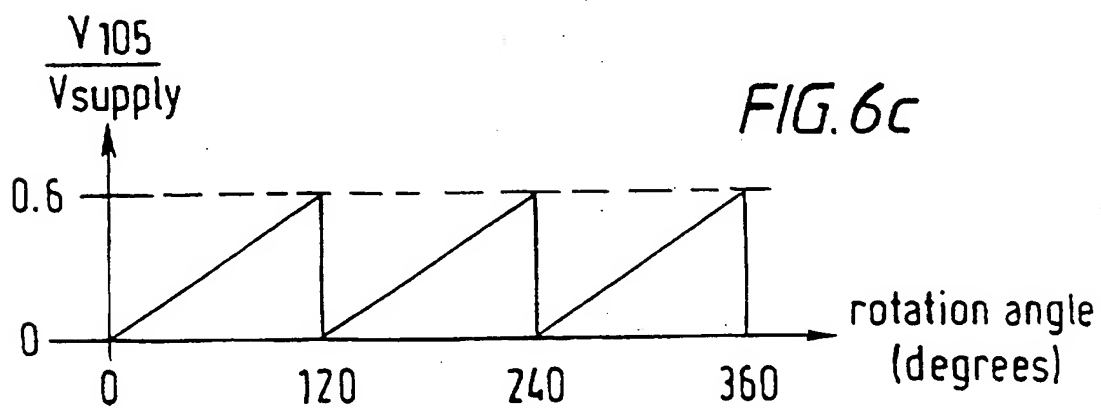
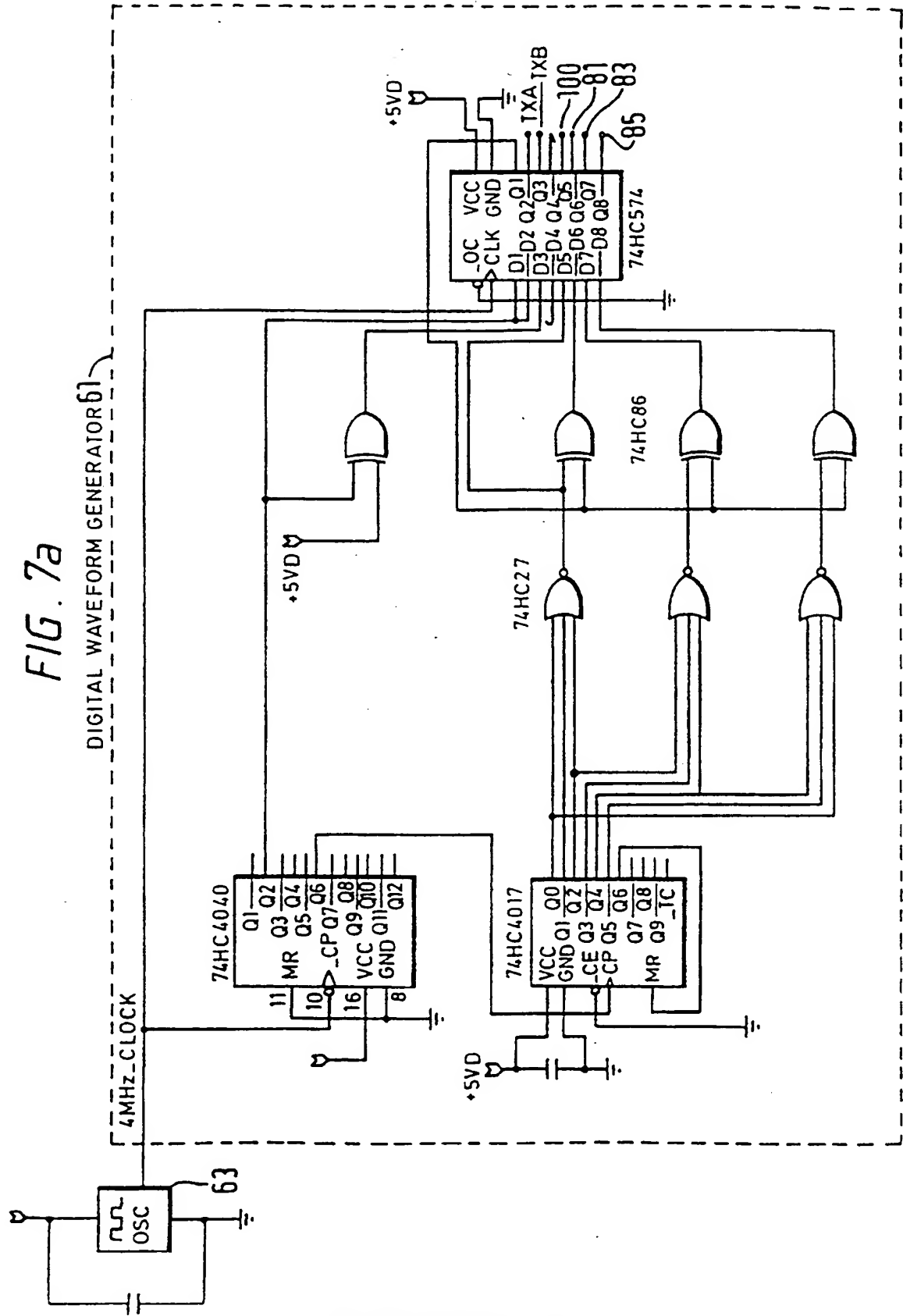
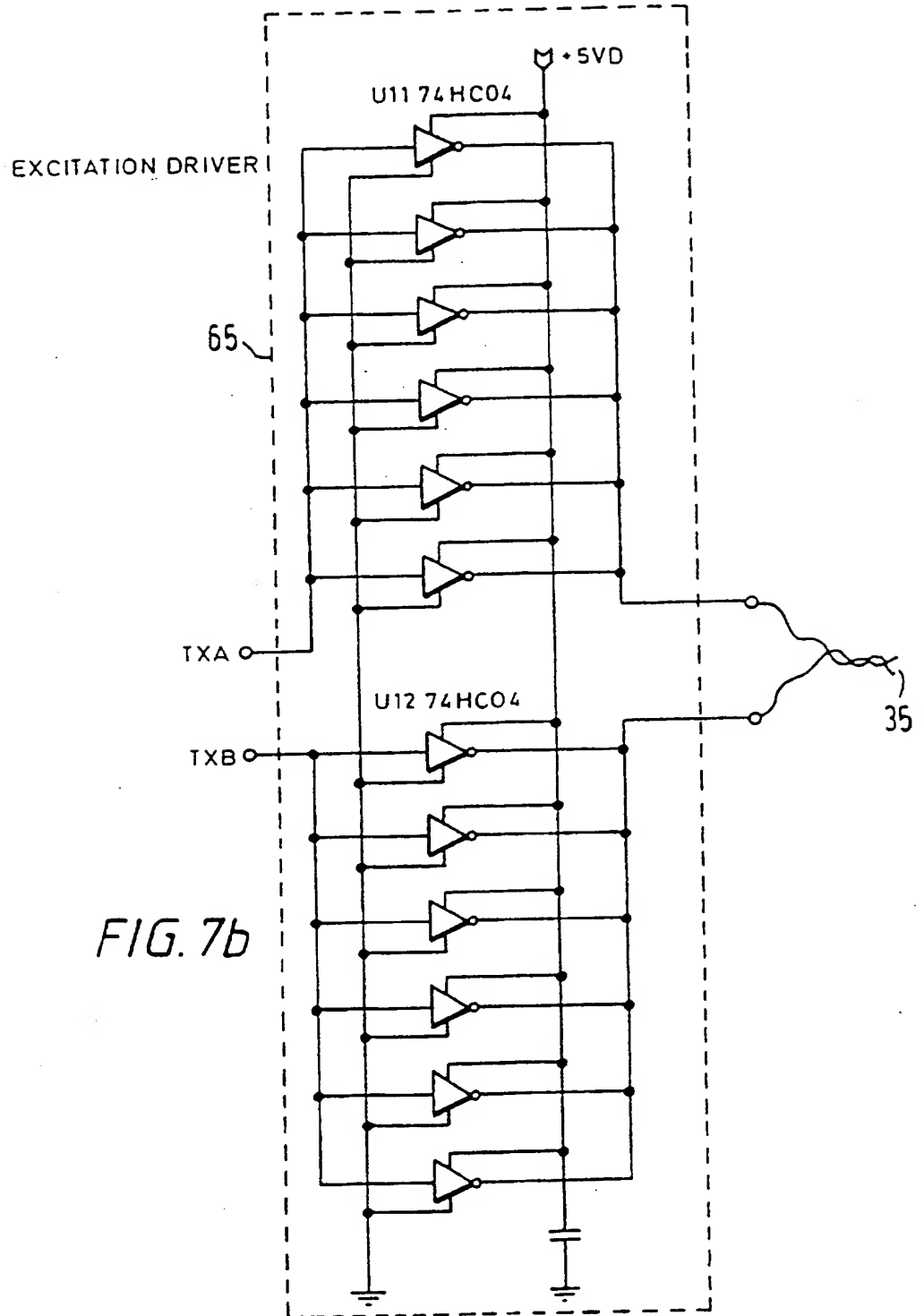
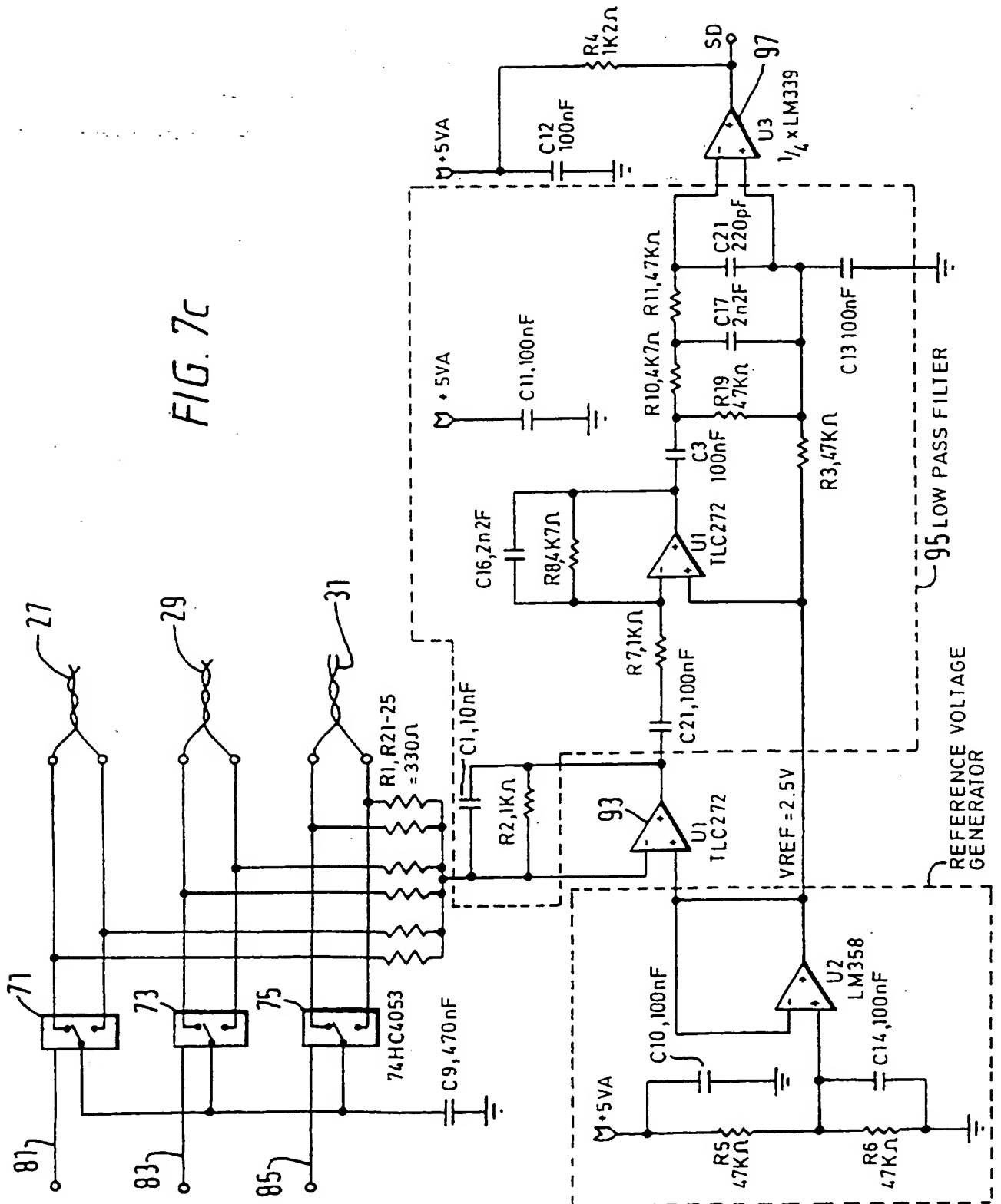


FIG. 6c







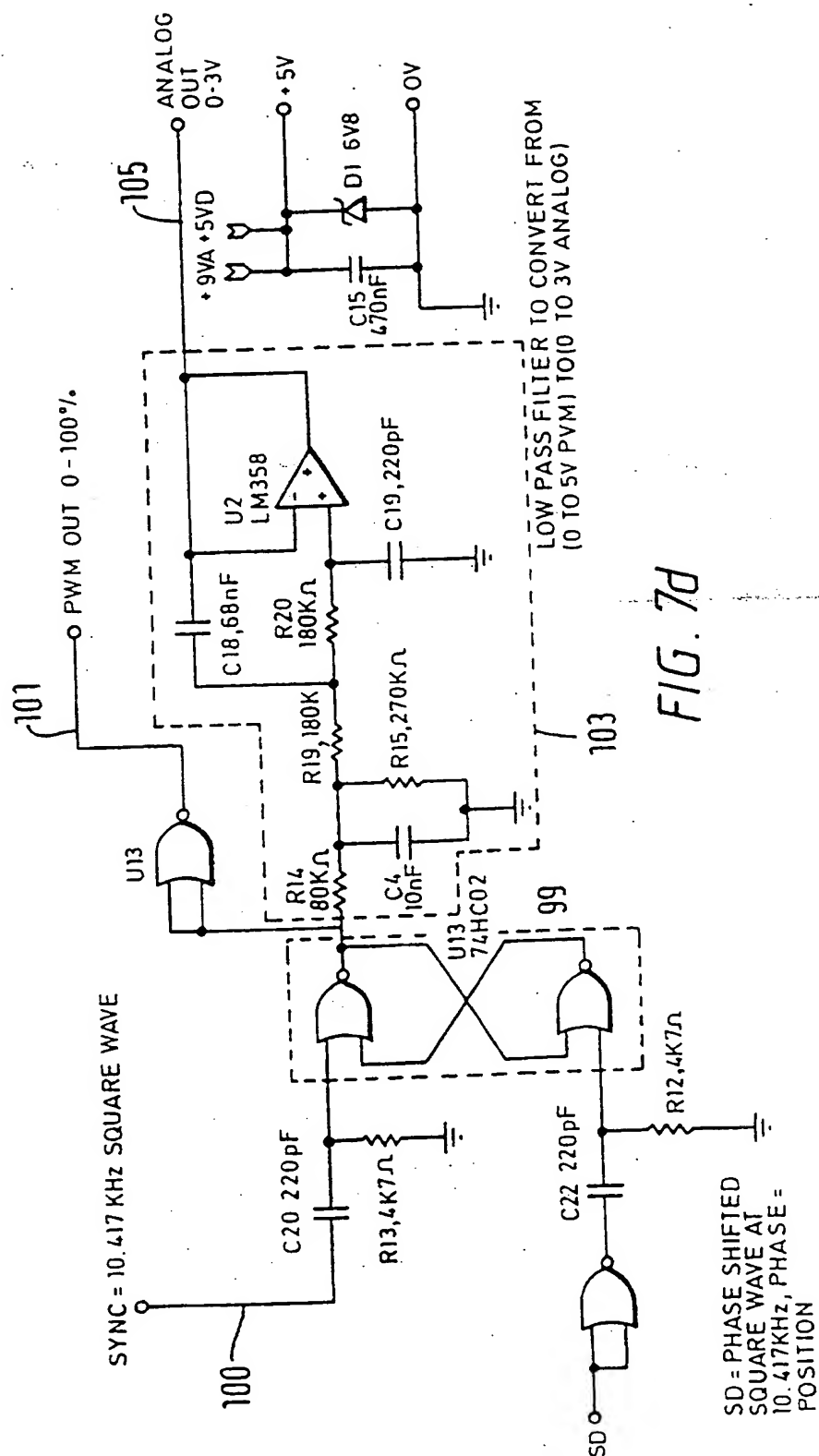


FIG. 7d



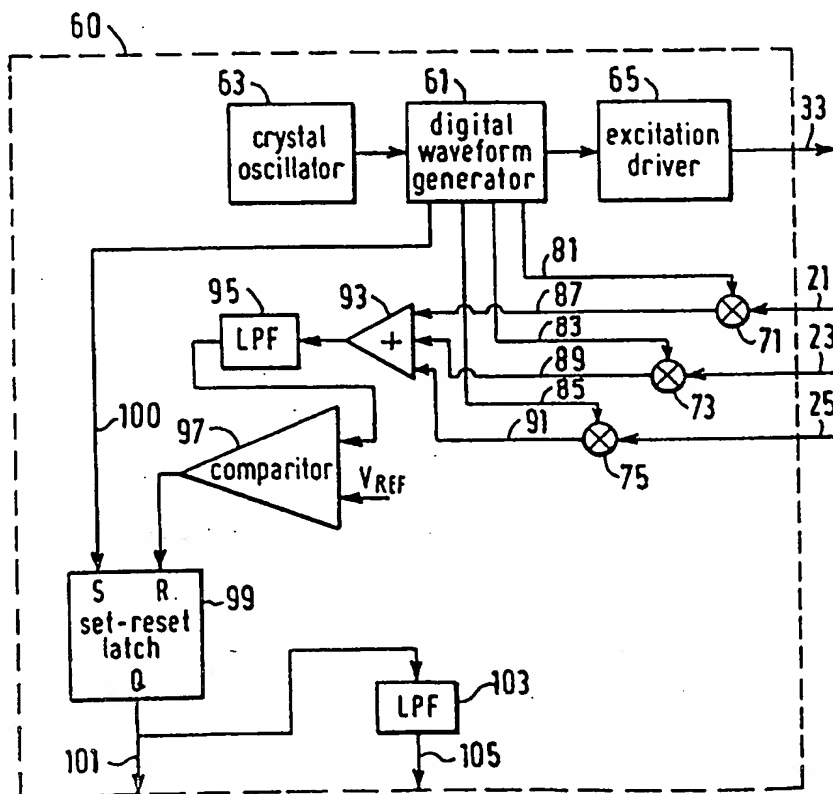
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| | | | |
|--|--|--|---|
| (51) International Patent Classification ⁶ : G01D 5/244 | | A3 | (11) International Publication Number: WO 98/00921 |
| | | | (43) International Publication Date: 8 January 1998 (08.01.98) |
| (21) International Application Number: PCT/GB97/01762 | | (81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). | |
| (22) International Filing Date: 30 June 1997 (30.06.97) | | Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments. | |
| (30) Priority Data: 9613673.4 28 June 1996 (28.06.96) GB | | (88) Date of publication of the international search report: 23 April 1998 (23.04.98) | |
| (71) Applicant (for all designated States except US): SCIENTIFIC GENERICS LIMITED [GB/GB]; Harston Mill, Harston, Cambridgeshire CB2 5NH (GB). | | | |
| (72) Inventors; and (75) Inventors/Applicants (for US only): ELY, David, Thomas, Eliot [GB/GB]; 45 Coleridge Road, Cambridge CB1 3PH (GB). DAMES, Andrew, Nicholas [GB/GB]; 74 Defreville Avenue, Cambridge CB4 1HU (GB). | | | |
| (74) Agent: BERESFORD, Keith, Denis, Lewis; Beresford & Co., 2-5 Warwick Court, High Holborn, London WC1R 5DJ (GB). | | | |

(54) Title: APPARATUS AND METHOD FOR PROCESSING SIGNALS OBTAINED FROM A POSITION ENCODER

(57) Abstract

Processing circuitry is provided for processing a plurality of signals received from sense coils (21, 23 and 25) forming part of a position encoder used to encode the relative positions of two relatively movable members. The position encoder is such that each of the plurality of signals from the sense coils varies sinusoidally with the relative position of the members but out of phase with respect to each other. The processing apparatus comprises mixers (71, 73 and 75) for multiplying each of the received signals with one of a corresponding plurality of periodic time varying signals, each having the same predetermined period and a different predetermined phase, and an adder (93) for adding the signals from the mixers. The phase of the mixing signals are chosen so that the output signal from the adder contains a single periodic component having the predetermined period whose phase varies with the relative position of the two members.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|----|--------------------------|----|--|----|--|----|--------------------------|
| AL | Albania | ES | Spain | LS | Lesotho | SI | Slovenia |
| AM | Armenia | FI | Finland | LT | Lithuania | SK | Slovakia |
| AT | Austria | FR | France | LU | Luxembourg | SN | Senegal |
| AU | Australia | GA | Gabon | LV | Latvia | SZ | Swaziland |
| AZ | Azerbaijan | GB | United Kingdom | MC | Monaco | TD | Chad |
| BA | Bosnia and Herzegovina | GE | Georgia | MD | Republic of Moldova | TG | Togo |
| BB | Barbados | GH | Ghana | MG | Madagascar | TJ | Tajikistan |
| BE | Belgium | GN | Guinea | MK | The former Yugoslav Republic of Macedonia | TM | Turkmenistan |
| BF | Burkina Faso | GR | Greece | | | TR | Turkey |
| BG | Bulgaria | HU | Hungary | ML | Mali | TT | Trinidad and Tobago |
| BJ | Benin | IE | Ireland | MN | Mongolia | UA | Ukraine |
| BR | Brazil | IL | Israel | MR | Mauritania | UG | Uganda |
| BY | Belarus | IS | Iceland | MW | Malawi | US | United States of America |
| CA | Canada | IT | Italy | MX | Mexico | UZ | Uzbekistan |
| CF | Central African Republic | JP | Japan | NE | Niger | VN | Viet Nam |
| CG | Congo | KE | Kenya | NL | Netherlands | YU | Yugoslavia |
| CH | Switzerland | KG | Kyrgyzstan | NO | Norway | ZW | Zimbabwe |
| CI | Côte d'Ivoire | KP | Democratic People's Republic of Korea | NZ | New Zealand | | |
| CM | Cameroon | KR | Republic of Korea | PL | Poland | | |
| CN | China | | | PT | Portugal | | |
| CU | Cuba | KZ | Kazakhstan | RO | Romania | | |
| CZ | Czech Republic | LC | Saint Lucia | RU | Russian Federation | | |
| DE | Germany | LI | Liechtenstein | SD | Sudan | | |
| DK | Denmark | LK | Sri Lanka | SE | Sweden | | |
| EE | Estonia | LR | Liberia | SG | Singapore | | |

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 97/01762

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01D5/244

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H03M G01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|----------------------------------|
| X | US 3 482 242 A (HARGROVE JAMES L) 2 December 1969 see figure 1 | 1-6, 8-19, 21-28, 33-35 |
| A | --- ELECTRICAL DESIGN NEWS, vol. 16, no. 12, 15 June 1971, pages 53-56, XP002045871 R. KLATT: "Phase of Digital Data Fixes Shaft Angle" see page 56, line 14 - line 26 | 3,16 |
| A | --- PATENT ABSTRACTS OF JAPAN vol. 010, no. 009 (P-420), 14 January 1986 & JP 60 165512 A (TOSHIBA KK), 28 August 1985, see abstract --- -/- | 7,20 |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

6 November 1997

Date of mailing of the international search report

25.02.98

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

VERHOOF, P

INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB 97/01762

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-28,30-35: Processing of position encoder/detector signals using demodulation combined with remodulation.
2. Claim 29 and dependent claims: Position detector with capacitive coupling.

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-28, 30-35

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Inter national Application No
PCT/GB 97/01762

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|---|-----------------------|
| A | <p>WO 95 31696 A (SCIENT GENERICS LTD ;DAMES ANDREW NICHOLAS (GB); ELY DAVID THOMAS) 23 November 1995 cited in the application see the whole document -----</p> | 30-32 |

INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No
PCT/GB 97/01762

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---------------------|----------------------------|---------------------|
| US 3482242 A | 02-12-69 | NONE | |
| WO 9531696 A | 23-11-95 | AU 679378 B | 26-06-97 |
| | | AU 2451395 A | 05-12-95 |
| | | CA 2189959 A | 23-11-95 |
| | | EP 0760087 A | 05-03-97 |